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Accurate calibration and optimized measurement: use of an achromatic compensator in rotating polarizer spectroscopic ellipsometry

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► To cite this version:

Laurent Broch, Aotmane En Naciri, Luc Johann. Accurate calibration and optimized measurement: use of an achromatic compensator in rotating polarizer spectroscopic ellipsometry. ICSE-3, 2003, Vienne, Austria. hal-02900945

HAL Id: hal-02900945

<https://hal.univ-lorraine.fr/hal-02900945>

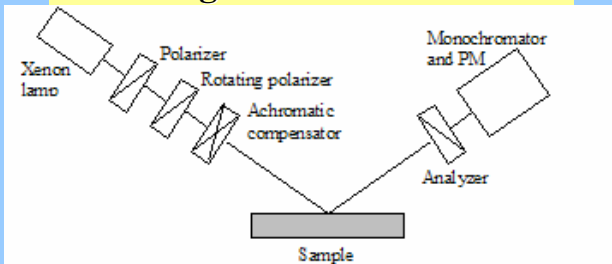
Submitted on 16 Jul 2020

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We describe an improvement of a Rotating Polarizer Ellipsometer in order to increase the sensitivity for the measurement of a transparent sample. We added a compensator, namely a quasi-achromatic retardation quarter wave plate on the 400-700nm spectral range. This new configuration is named Polarizer Rotating-Polarizer Compensator Spectroscopic Ellipsometer (PRPCSE). We present a method for calibration and the advantages for measurement of the transparent materials. This method is applied to CuCl nanocrystals embedded in a NaCl transparent matrix.

Diagram of PRPCSE



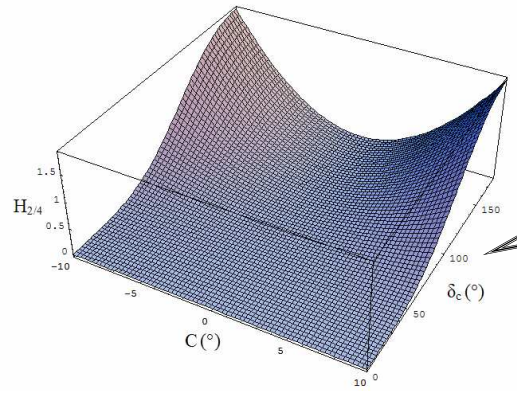
Independent of the sample used and the gain of the ellipsometer

two-zone measurements for eliminating systematic errors

The detected photocurrent has the form :
 $I = \alpha_0 + \alpha_{2c} \cos 2\omega t + \alpha_{2s} \sin 2\omega t + \alpha_{4c} \cos 4\omega t + \alpha_{4s} \sin 4\omega t$
 where $P_1 = \omega t$ is the azimuth of the rotating polarizer.

CALIBRATION

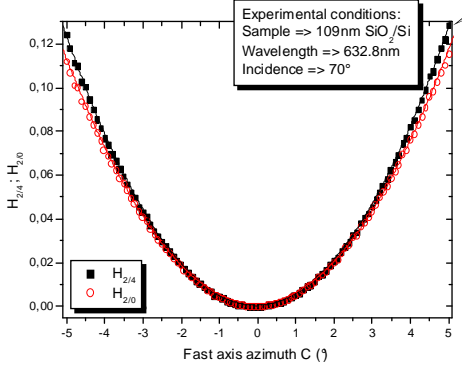
The methods for the calibration of the polarizers and analyzer are exactly the same as for the PRPSE ellipsometer. The PRPSE is the same configuration without the compensator. The residue calibration for the compensator is a powerful method because it is independent of the phase shift of the compensator.



This configuration allows to extract the ellipsometric parameters by using 3 sets of the analyzer and compensator positions. The influence of **the gain is eliminating** by using the modified coefficients as $\beta_i = \alpha_i / (\alpha_{2c} - 2 \alpha_{4c})$ where $i = 2c, 2s, 4c, 4s$ and $P = 0^\circ$. **The average incident light irradiance is not used** for the measurements.

Simulation of the ratio $H_{2/4} = (\alpha_{2c}^2 + \alpha_{2s}^2) / (\alpha_{4c}^2 + \alpha_{4s}^2)$ when the fast axis azimuth (C) is close to the plane of incidence. $H_{2/4} \approx 64 C^2 \sin^2(\delta_c/2)$.

Experimental data for the calibration of the compensator (analyzer = 0° and polarizer = 90°). 2 methods are possible: $H_{2/4}$ or $H_{2/0}$.



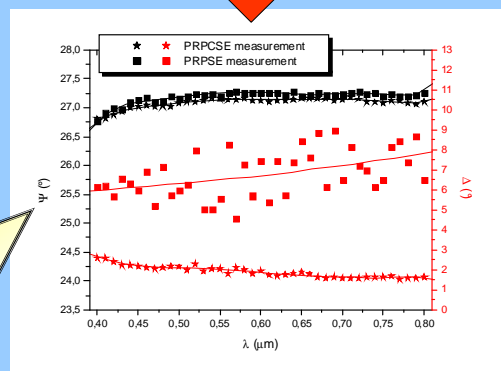
Experimental measurements of CuCl nanocrystals embedded in a NaCl transparent matrix

- The PRPSE configuration (with optimized tracking method) allows to measure $\tan \Psi$ and $\cos \Delta$ (experimental errors are proportionnal to $\sin^{-1} \Delta$).
- The PRPCSE configuration allows to measure $\tan \Psi$ and $\tan \Delta$ (experimental errors are proportionnal to $\cos^2 \Delta$).

MEASUREMENT

Compensator fast axis position	Analyzer position	Measured Fourier parameters
$C = \pm 45^\circ$	$A = 0^\circ$	$\beta_{2c} = 2 \cos^2 \frac{\delta_c}{2}, \beta_{4c} = -\frac{\cos \delta_c}{2}, \beta_{2s} = \beta_{4s} = 0$
$C = 0^\circ$	$A = \pm 45^\circ$	$\beta_{2c} = 2 \sin^2 \Psi, \beta_{4c} = -\frac{\cos 2\Psi}{2}$
$C = 90^\circ$	$A = \pm 45^\circ$	$\beta_{2c} = 2\beta_{4c} = \text{sgn } A \sin 2\Psi \cos(\Delta \pm \delta_c \cos 2C)$
$C = \pm 45^\circ$	$A = \pm 45^\circ$	$\beta_{2c} = 1 - \cos \delta_c \cos 2\Psi + \text{sgn } A \text{sgn } C \sin \Delta \sin \delta_c \sin 2\Psi$
	$A = \pm 45^\circ$	$\beta_{4c} = \frac{1}{2} (\cos \delta_c \cos 2\Psi + \text{sgn } A \text{sgn } C \sin \Delta \sin \delta_c \sin 2\Psi)$ $\beta_{4s} = \frac{1}{2} \text{sgn } A \cos \Delta \sin 2\Psi$

- From the first set of analyzer and compensator positions we deduce $\cos \delta_c$.
- The second set allows to determine the parameter $\tan \Psi$ and if necessary $\cos(\Delta \pm \delta_c)$.
- Finally the third set consists in determining $\tan \Delta$.



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